Investigating the influence of dynamic effects on two-phase flow at the pore scale with fast laboratory-based X-ray micro-CT

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ABSTRACT

Recent studies have provided insight in the dynamics of pore-scale events during two-phase flow in porous media [1,2]. Specifically, during drainage, discrete filling events (so-called Haines jumps) have been shown to possess complex transient dynamics, with high local flow velocities (up to 1m/s). Furthermore, a Haines jump turns out to be a non-local process, as such a jump can have a zone of influence which extends over multiple pores. However, the importance of these transient dynamics to the resulting properties on a larger, representative scale in real three-dimensional pore spaces is still unclear. In this work, we investigate this by visualizing the evolution of the fluid distribution during drainage in a Bentheimer sandstone, without having to stop the flow between every two scans, and comparing the experimental data to a static model description of the filling sequence.
Over the last few years, it has become possible to monitor the pore-scale distribution of fluid phases during multi-phase flow over time by performing 4D X-ray micro-computed tomography (micro-CT) experiments [3,4]. The time resolution of these experiments is important, as short acquisition times allow to study the fluid distribution before and after single (or few) filling events without interrupting the flow. At synchrotron beam lines, (sub-)second time resolutions are attainable, but the scarcity of synchrotron beam time limits the amount of such experiments. Laboratory-based micro-CT systems are much cheaper and therefore widely available, but most systems have a much lower time resolution, on the order of tens of minutes. Nonetheless, new developments in laboratory-based micro-CT hardware and software are opening the door to time resolutions on the order of seconds.
In this work, we present experiments in which two-phase (oil-water) flow in Bentheimer sandstone is visualized using a laboratory-based micro-CT set-up at Ghent University's Centre for X-ray Tomography. The acquisition time for a complete 360 degree scan is 12 seconds, but continuous scanning allows us to further increase time resolutions. We are therefore able to capture the evolution of the pore-scale distribution of oil during drainage, without interrupting the oil flow in between scans. We capture information on single pore-filling cascades, which we compare to a quasi-static invasion-percolation description of the filling sequence. Even though time resolutions are still insufficient to capture the transient dynamics, the experiments allow us to assess their influence on the resulting fluid configuration in the pore space. It is this configuration which largely determines the macroscopic petrophysical properties of the rock in question (e.g. relative permeability, capillary pressure curve, hysteresis properties, etc.).

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